BIRCH, STEWART, KOLASCH & BIRCH, LLP

TERRELL C. BIRCH
RAYMOND C. STEWART
JOSEPH A. KOLASCH
JAMES M. SLATTERY
BERNARD L. SWEENEY*
MICHAEL K. MUTTER
CHARLES GORENSTEIN
GERALD M. MURPHY, JR.
LEONARD R. SVENSSON
TERRY L. CLARK
ANDREW D. MEIKLE
MARC S. WEINER
JOE McKINNEY MUNCY
ROBERT J. KENNEY
DONALD J. DALEY
JOHN W. BAILEY
JOHN A. CASTELLANO, III
GARY D. YACURA

OF COUNSEL:
HERBERT M. BIRCH (1905-1996)
ELLIOT A. GOLDBERG*
WILLIAM L. GATES*
EDWARD H. VALANCE
RUPERT J. BRADY (RET.)*
F. PRINCE BUTLER
FRED S. WHISENHUNT

*ADMITTED TO A BAR OTHER THAN VA.

INTELLECTUAL PROPERTY LAW
8110 GATEHOUSE ROAD
SUITE 500 EAST
FALLS CHURCH, VA 22042-1210
USA

(703) 205-8000

FAX: (703) 205-8050
(703) 698-8590 (G IV)

e-mail: mailroom@bskb.com
web: http://www.bskb.com

CALIFORNIA OFFICE
COSTA MESA, CALIFORNIA

THOMAS S. AUCHTERLONIE
JAMES T. ELLER, JR.
SCOTT L. LOWE
MARK J. NUELL, PH.D.
D. RICHARD ANDERSON
PAUL C. LEWIS
MARK W. MILSTEAD*
JOHN CAMPA*
RICHARD J. GALLAGHER

REG PATENT AGENTS:
FREDERICK R. HANDREN
MARYANNE ARMSTRONG
MAKI HATSUMI
MIKE S. RYU
CRAIG A. McROBBIE
GARTH M. DAHLEN, PH.D.
LAURA C. LUTZ
ROBERT E. GOOZNER, PH.D.
HYUNG N. SOHN
MATTHEW J. LATTIG
ALAN PEDERSEN-GILES
JUSTIN D. KARJALA
C. KEITH MONTGOMERY
TIMOTHY R. WYCKOFF
HERMES M. SOYEZ, PH.D.
KRISTI L. RUPERT, PH.D.

jc806 U.S. PTO 08/31/00

jc806 U.S. PTO 09/652154 08/31/00

Date: August 31, 2000
Docket No.: 0717-0444P

Assistant Commissioner for Patents
Box PATENT APPLICATION
Washington, D.C. 20231

Sir:

As authorized by the inventor(s), transmitted herewith for filing is a patent application applied for on behalf of the inventor(s) according to the provisions of 37 CFR 1.41(c).

Inventor(s): KUBO, Noboru
ZHANG, Xiamang; OKUHATA, Hiroyuki
NIWA, Akimasa

For: METHOD FOR CORRECTING LIGHTNESS OF IMAGE

Enclosed are:

X A specification consisting of 32 pages

X 15 sheet(s) of formal drawings

___ Certified copy of Priority Document(s)

X Executed Declaration in accordance with 37 CFR 1.64 will follow

___ A verified statement to establish small entity status under 37 CFR 1.9 and 37 CFR 1.27

___ Preliminary Amendment

X Information Sheet

X Information Disclosure Statement, PTO-1449 with reference(s)

___ Other _____

The filing fee has been calculated as shown below:

			LARGE ENTITY			SMALL ENTITY	
FOR	NO. FILED	NO. EXTRA	RATE	FEE		RATE	FEE
BASIC FEE	********** ********** **********	********** ********** **********	***** ***** *****	$690.00	or	**** **** ****	$345.00
TOTAL CLAIMS	7 - 20 =	0	x18 =$	0.00	or	x 9 = $	0.00
INDEPENDENT	1 - 3 =	0	x78 =$	0.00	or	x 39 = $	0.00
MULTIPLE DEPENDENT CLAIM PRESENTED no			+260 = $	0.00	or	+130 = $	0.00
			TOTAL $	690.00		TOTAL $	0.00

_X_ The application transmitted herewith is filed in accordance with 37 CFR 1.41(c). The undersigned has been authorized by the inventor(s) to file the present application. The original duly executed patent application together with the surcharge will be forwarded in due course.

_X_ A check in the amount of $ 690.00 to cover the filing fee and recording fee (if applicable) is enclosed.

___ The Government Filing Fee will be paid at the time of completion of the filing requirement.

___ Please charge Deposit Account No. 02-2448 in the amount of $_____. A triplicate copy of this transmittal form is enclosed.

_X_ Send Correspondence to: BIRCH, STEWART, KOLASCH & BIRCH, LLP
P. O. Box 747
Falls Church, Virginia 22040-0747

0717-0444P

___ No fee is enclosed.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. 1.16 or under 37 C.F.R. 1.17; particularly, extension of time fees.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

By _____
TERRELL C. BIRCH
Reg. No. 19,382
P. O. Box 747
Falls Church, Virginia 22040-0747

(703) 205-8000
TCB/amr

METHOD FOR CORRECTING LIGHTNESS OF IMAGE

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

The present invention relates to a lightness correction method which is capable of correcting a digital still color image taken by a digital camera, a surveillance camera, or the like into the optimal dynamic range required.

2. DESCRIPTION OF THE RELATED ART:

The retinex method has been proposed as a method for correcting lightness information, color information, or the like of a digital still color image. The retinex method models a retina of an eye. In this method, local information of an image is used to correct lightness of the image having biased dynamic range (dynamic characteristic). Specifically, lightness is increased for a portion of an image having low lightness while lightness is decreased for a portion of the image having high lightness, so that the image becomes easier to perceive.

Examples of the retinex method include a single-scale retinex (Daniel J. Jobson, et al.,

"Properties and Performance of a Center/Surround Retinex", IEEE Trans. on Image Processing, vol. 6, pp. 451-462, March 1997) and a multiscale retinex (Daniel J. Jobson et al., "A Multiscale Retinex for Bridging the Gap Between Color Images and the Human Observation of Scenes", IEEE Trans. on Image Processing, vol. 6, pp. 956-976, July 1997).

In the single-scale retinex, the spectral band component $I_i(x,y)$ $(i=1,2,\cdots)$ of a pixel $I(x,y)$ (hereinafter referred to as a subject pixel) in an original image is corrected by a surround function $F(x,y)$ obtained based on information on surround pixels. The result of the retinex operation is represented by

$$R_i=\log(I_i(x,y))-\log[F(x,y)*I_i(x,y)] \cdots (1)$$

where "*" denotes the convolution operation.

In this case, $F(x,y)$ is represented by

$$F(x,y)=Ke^{-r^2/c^2} \cdots (2)$$

where r denotes the distance between a pixel and a surround

pixel ($r^2=x^2+y^2$), c denotes the scale parameter, and K is the scala coefficient and selected such that $F(x,y)dxdy=1$, i.e., the total of the surround function is equal to 1.

The result of the single-scale retinex operation, $R_i(x,y)$, is obtained by expressions (1) and (2). Thereafter, the result $R_i(x,y)$ is converted into an appropriate dynamic range by correcting with correction parameters gain and offset, using the following expression (3). A corrected result of a retinex operation, I_{R_i}, is represented by

$$I_{R_i}=Gain\times R_i+Offset \cdots (3).$$

Thus, in the single-scale retinex (SSR), the spectral band component of a subject pixel is processed based on the surround function. The multiscale retinex (MSR) provides the retinex having N scales for the spectral band component Ii of a subject pixel. In the MSR, the result of the MSR operation is a weighted sum of the results of the SSR operations having the N scales. The result of each SSR is weighted by the weight w_n. The result of the MSR, R_{MSR_i} is represented by

$$R_{MSR_i} = \sum_{n=1}^{N} \omega_n R_{ni} \quad \cdots\cdots (4)$$

Similar to the SSR, the result of the MSR, R_{MSR_i}, calculated by expression (4) is converted into an appropriate dynamic range by correcting with the correction parameters gain and offset. A corrected result of the MSR operation, I_{MSR_i}, is represented by

$$I_{MSR_i} = Gain \times R_{MSRi} + Offset \cdots (5).$$

In the MSR, the calculation of the SSR is performed a given number of times, which is equal to the number of scales (N), so as to correct a subject pixel. In other words, the N surround functions are calculated for a pixel. Therefore, if the number of scales is large, about half of the pixels in the entire image may need to be referred to as the surround pixels so as to perform the MSR operation for a subject pixel. The number of pixels to be referred to increases in proportion to the second power of the length of a scale as well as the length of the image.

The MSR needs the log operation, the exponential operation, and the sum-of-products operation which are

required in the convolution operation. The increased number of surround pixels to be referred leads to a vast amount of calculation. The number of accesses to a memory which stores the results of the operations is increased. Moreover, a large volume of memory is required to store information on the two-dimensional surround pixels, intermediate results of the operations, and the like, thereby reducing cost efficiency. The increased number of accesses to a memory is also likely to increase the processing time.

In particular, recently, high picture-quality digital cameras having about one or two mega pixels have been developed. Such cameras require longer time for the MSR operation.

SUMMARY OF THE INVENTION

According to an aspect of the present invention, a method for correcting lightness of an image using a multiscale retinex is provided, wherein lightness of a subject pixel of an original image is corrected using a convolution operation of a surround function and surround pixels with respect to the subject pixel of the original

image, and the convolution operation is performed over a plurality of scales; and the surround function has a simplified model such that a value of the surround function is changed in a stepwise way along two axes orthogonal to each other.

In one embodiment of this invention, a sum of image information on the surround pixels positioned at the same distance from the subject pixel and the surround function based on a one-dimensional scale size, the value of the surround function changing in a stepwise way, are subjected to the convolution operation, and a result of the convolution operation is used as a result of another convolution operation.

In one embodiment of this invention, the image information on the surround pixels are read as horizontal and vertical vector components changing along the two axes in a stepwise way.

In one embodiment of this invention, a scala coefficient K of the surround function used in the convolution operation is calculated based on data dependency on the scala coefficient K previously

calculated.

In one embodiment of this invention, the number of the surround pixels to be read out is decreased to reduce the calculation amount of sum-of-products operation in the convolution operation.

In one embodiment of this invention, only one subject pixel is selected with respect to a pixel group consisting of a number of pixels; the convolution operation is performed for the subject pixel; the result of the convolution operation is used as a result of the convolution operation for the other pixels in the pixel group.

In one embodiment of this invention, the log operation in the multiscale retinex is approximately calculated based on a predetermined graph.

Thus, the invention described herein makes possible the advantages of providing a method for correcting lightness of an image, in which (1) the calculation amount of the MSR can be reduced, thereby significantly reducing the processing time; (2) the

memory amount for storing the results of the operations can be reduced, thereby obtaining a low-cost apparatus.

These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures **1A** and **1B** are diagrams showing a surround function.

Figures **1C** and **1D** are diagrams showing a simplified model of the surround function shown in Figures **1A** and **1B**.

Figure **2** is a diagram for explaining a reduction of the simplified model of the surround function into one dimension.

Figure **3** is a diagram for explaining the convolution operation in a MSR based on the simplified model of the surround function.

Figure 4 is a diagram for explaining an overlap of surround pixels in the simplified model of the surround function.

Figure 5A is a diagram for explaining a scale to be divided into horizontal and vertical vector components in the simplified model of the surround function.

Figure 5B is a diagram for explaining the horizontal vector component.

Figure 5C is a diagram for explaining the vertical vector component.

Figure 6A is a diagram for explaining an overlap of the horizontal vector component of surround pixels.

Figure 6B is a diagram for explaining an overlap of the vertical vector component of surround pixels.

Figure 7 is a diagram for explaining generation of image information on a surround pixel from the horizontal and vertical vector components.

Figures **8A** and **8B** are diagrams for explaining a dependency relationship of image information in calculation of a scala coefficient K.

Figure **9** is a block diagram for explaining the updating of the scala coefficient K.

Figure **10** is a flowchart for explaining a method of updating the scala coefficient K.

Figure **11** is a diagram for explaining a method of reducing the number of times of sampling image information.

Figure **12** is a diagram for explaining a method of reducing the number of times of the convolution operation.

Figure **13A** is a graph used for simplifying the log operation.

Figure **13B** is a control diagram of the the log operation using the graph shown in Figure **13A**.

Figure **14** is a block diagram showing an example of a correction system used for performing a method according to the present invention for correcting lightness of an image.

Figure **15** is a flowchart for explaining the operation of the correction system shown in Figure **14**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings.

In a lightness correction method according to this invention, the spectral band components of a pixel in an original image are processed by the MSR to correct the lightness of the pixel. The MSR uses a surround function selected based on the scale size. The surround function is also based on the distance between a subject pixel which is the subject of the lightness correction and surround pixels which surround the subject pixel. In a typical MSR, a surround function as shown in Figure **1A** is used. As shown in Figure **1B**, the surround function is digitized

to have discrete values corresponding to the respective pixels each of which is defined as a square region.

On the other hand, in the lightness correction method of this invention, the MSR uses a surround function as shown in Figure **1C**. This surround function is a simplified model of the surround function as shown Figure **1A**. As shown in Figure **1C**, the value of the surround function is changed in a stepwise way along the two axes (x-axis and y-axis) orthogonal to each other. As shown in Figure **1D**, the surround function is digitized to have discrete values corresponding to the respective pixels each of which is defined as a square region.

In the discrete surround function shown in Figure **1D**, the value of the surround function is decreased as a surround pixel is positioned away from a subject pixel along the two directions (x-axis direction and y-axis direction) orthogonal to each other. In addition, the value of the surround function is decreased in a stepwise way so that the further the position of the surround pixel, the lesser the contribution of the image information of the surround pixel on the retinex output. For example, Figure **2** shows a surround function having an axa scale

(corresponding to axa pixels). The further the position of a surround pixel away from a subject pixel **11** along each of the x-axis direction and the y-axis direction, the smaller the corresponding value of the surround function. The value of the surround function is decreased in a stepwise way. The values of the surround function for the pixels positioned on the circumference of a square having the center on the subject pixel **11** are equal to each other.

As a result, in the scale of axa pixels, the pixels having the same value of a surround function can be added up when performing the convolution operation between the surrounding function and the center and surround pixels. For this reason, the two dimensional convolution operation can be replaced with a one-dimensional convolution operation.

Therefore, in the scale of axa pixels, for example, when the convolution operation is performed for the overall pixels in the two-dimensional region, the number of summations of products is axa. In this invention, the number of summations of products in the convolution operation is decreased to a/2. For this reason, the time

consumed by the operation is significantly reduced. In addition, the memory for storing the intermediate data is significantly reduced since summation of products for the surround pixels in the one-dimensional region, and the like are stored.

Thus, when the simplified model of the surround function is used, the image information of the surround pixels does not need to be stored for all scales as shown in Figure 3. In this case, the image information of the surround pixels for a large scale includes the image information of the surround pixels for a smaller scale (small and middle). Therefore, when the image information of the surround pixels only for the maximum scale is stored, any smaller scale having a reduced size do not require a new calculation. As a result, it is possible to avoid overlaps of the same image information of the surround pixels between different scales, thereby significantly reducing the required memory capacity.

Thus, in the MSR using the simplified model of the surround function, the calculation amount and the memory capacity for the convolution operation substantially do not depend on the size of a scale and the number of scales

and is therefore reduced to as small as those required in the SSR.

Further, in the simplified model of the surround function, a portion of the image information which has been used in the previous convolution operation is used in the current convolution operation using the same scale. For example, as shown in Figure 4, it is assumed that the image information of surround pixels 12 positioned along the y-axis direction and the x-axis direction while equally spaced in the x-axis direction and the y-axis direction, respectively (indicated by shading in Figure 4) have been used in the previous convolution operation. In the current convolution operation, when a subject pixel 13 is adjacent to a previous subject pixel 11 of the previous operation in the x-axis direction, surround pixels 14 surrounded by a black border are used in the current convolution operation. In this case, the result of the previous convolution operation is used again for four surround pixels positioned each on the upper and lower sides along the x-axis.

For this reason, there is an overlaps of 8 (50%) pixels between the 16 surround pixels 12 with respect to

the subject pixel **11** and the 16 surround pixels **14** with respect to the subject pixel **13**, when the subject pixels **11** and **13** are adjacent to each other. Thus, 50% of the image information of the surround pixels **12** which was used in the previous operation can be used again, thereby significantly reducing the number of accesses to a memory.

The image information of the surround pixels may be obtained by synthesizing a horizontal vector component obtained by scanning along the x-axis direction and a vertical vector component obtained by scanning along the y-axis direction. For example, as shown in Figure **5A**, it is assumed that a scale is composed of 7×7 pixels. Image information on surround pixels in a portion of the scale shown in Figure **5B** is read out as a horizontal vector component **10a** by scanning along the x-axis direction. Image information on surround pixels in a portion of the scale shown in Figure **5C** is read out as a vertical vector component **10b** by scanning along the y-axis direction. Thereafter, the horizontal vector component **10a** and the vertical vector component **10b** are synthesized to obtain the entire image information on the surround pixels for a current subject pixel.

In this case, the horizontal vector component **10a** is composed of a subject pixel **11**; two sets of 3 surround pixels adjacent to each other, each set positioned on the y-axis side of the subject pixel **11** opposite each other; two sets of 5 surround pixels adjacent to each other, each set positioned on the outer side (y-axis side) of the respective sets of 3 surround pixels; and two sets of 7 surround pixels adjacent to each other, each set positioned on the outer side (y-axis side) of the respective sets of 5 surround pixels.

The vertical vector component **10b** is composed of the image information on the 7×7 pixels except for the subject pixel **11** and surround pixels included in the horizontal vector component **10a**, i.e., 18 pixels.

As described above, the image information on the surround pixels for the current subject pixel are divided into the horizontal and vertical vector components **10a** and **10b** which are in turn read separately. In this case, when the current subject pixel is adjacent to the previous subject pixel in the x-axis direction as shown in Figure **6A**, there is a large overlap in each level of the

surround function between the horizontal vector components of the current scale and the previous scale (high overlap ratio) (the overlap portions between the surround pixels indicated by shading and the surround pixels surrounded by the black border). When the current subject pixel is adjacent to the previous subject pixel in the y-axis direction as shown in Figure 6B, there is a large overlap in each level of the surround function between the vertical vector components of the current scale and the previous scale (high overlap ratio) (the overlap portions between the surround pixels indicated by shading and the surround pixels surrounded by the black border). The information on the surround pixels is hold as a sum of information on the whole pixels in each level of the surround function.

Accordingly, as shown in Figure 7, the information on the surround pixels is updated using the image information on the overlapped surround pixels. When the current subject pixel is shifted from the previous subject pixel by one pixel toward the downstream in the x-axis scanning direction (to the right), the overlaps between the current and previous horizontal vector components at each level of the surround function

are used again for the updating. Similarly, when the current subject pixel is shifted from the previous subject pixel by one pixel toward the downstream in the y-axis scanning direction (to the bottom), the overlaps between the current and previous vertical vector components at each level of the surround function are used again for the updating. Image information on pixels of the current horizontal and vertical vector components, which pixels are not overlapped with those of the previous horizontal vertical vector components, are newly read out at each level of the surround function. The image information on the overlapped pixels and the new pixels are added with each other. Thus, one-dimensional image information on the overall surround pixels at each level of the surround function is generated for the current subject pixel.

Thus, the number of accesses to a memory is significantly reduced when the image information on the surround pixels is obtained. Therefore, it is possible to significantly reduce the processing time for obtaining the image information.

The overlap ratio of the image information between the surround pixels for the current subject pixel and the

surround pixels for the previous subject pixel at each level of the surround function is the most efficient when a subject pixel is shifted by one pixel along the x-axis and then is shifted by one pixel in the y-axis direction. In this case, a buffer is required for holding the vertical vector component of the image information of the surround pixels which is read while the subject pixel is shifted along the x-axis direction.

After image information on surround pixels at each level of the surround function is obtained for a current pixel, the surround function F(x,y) is calculated in accordance with expression (2). The scala coefficient K used in the calculation of the surround function F(x,y) is designed to obtain $\iint F(x,y)dxdy=1$. The value of K which is obtained in the previous calculation is utilized in the current calculation so as to calculate K at a high speed. The scala coefficient K is updated based on the data dependency between the scala coefficient K of the previous calculation and the scala coefficient K of the current calculation.

Referring to Figure **8A**, a subject pixel **11** is close to a corner of an image frame **15**. Reference

numeral **16** indicates a region which has a subject pixel **11** and over which the scala coefficient K is calculated and the convolution operation is performed. As shown in Figure **8A**, a part of the region **16** lies outside the image frame **15**. The scala coefficient K is corrected based on the surround function in a part of the region **16** which lies inside the image frame **15**. For another example, referring to Figure **8B**, a subject pixel **13** is adjacent to the subject pixel **11** in the x-axis direction. When the scala coefficient K is calculated for the subject pixel **13**, values of the surround function in the region **17** positioned inside the image frame **15** is used for the subject pixel **13**.

Accordingly, when the scala coefficient K is calculated for the subject pixel **13**, only values of the surround function corresponding to pixels **18** along the y-axis direction in the image frame **15** are additionally used for calculating the scala coefficient K from the subject pixel **11** as shown in Figure **8B**. With the data dependency, the scala coefficient K for the subject pixel **11** is utilized for updating the scala coefficient K for the subject pixel **13**.

The scala coefficient K is specifically updated as follows. Referring to Figure **9**, the values of the surround function which have been used for the previous subject pixel are stored in a one-dimensional table. The values of the surround function used for updating the scala coefficient K are selected based on the relationship between the position of the current subject pixel relative to the image frame and the scale size.

Figure **10** is a flowchart showing the updating of the scala coefficient K. Initially, it is determined whether the updating of the scala coefficient K is required based on the coordinate (x,y) of the subject pixel and the scale size (step **S1** in Figure **10**). Specifically, whether the scale for the subject pixel lies outside the image frame is determined based on the position of the subject pixel and the scale size. If so, the scala coefficient K is updated as follows. The surround function is calculated based on the coordinate (x,y) of the subject pixel (step **S2**). The scala coefficient K is updated on the calculated surround function (step **S3**).

In this case, as described above, the scala

coefficient K is calculated by scanning in a way similar to the scanning for reading out the horizontal and vertical vector components of the surround pixels. This requires only a buffer for holding the surround function for a current subject pixel.

Further, the number of times of sampling the image information on the surround pixels may be reduced as much as the picture quality of the image is not degraded, thereby significantly reducing the calculation amount. Specifically, when F(x,y)*I(x,y) in expression (1) is calculated, image information on some surround pixels is appropriately omitted as shown in Figure 11, thereby significantly reducing the number of times of sampling the image information on the surround pixels and the calculation amount. For instance, image information on one surround pixel is sampled for 16 (4×4) surround pixels.

Further, similar to the case when the number of times of sampling the image information on the surround pixels, part of the convolution operation may be omitted as long as the picture quality is not degraded, thereby reducing the calculation amount. To this end, the second

term of the retinex operation is carried out for only one pixel per 16 (4×4) surround pixels constituting a square group of pixels as shown in Figure **12**. The calculation result for the selected pixel is used for the second term of the retinex operation for each of the other 15 surround pixels when it is selected as a subject pixel. This leads to a significant reduction in the calculation amount of the convolution operation.

The log operation may be approximated by the sum-of-products operation so as to further reduce the calculation amount. Referring to Figure **13A**, the operation of y=log x in different ranges along the x-axis is approximated by lines having different gradients. Referring to Figure **13B**, the gradient of a line and the y intercept are calculated for a value of x. The calculated gradient and y intercept are a multiplier and an addend, respectively. A vast number of indexes do not need to be prepared for providing for a dynamic range of an appropriate display.

Figure **14** shows an example of a lightness correction system in which the above-described lightness correction method is practiced. The lightness

correction system includes a memory **21** for storing information on an original image; a fast MSR operation apparatus **22**; and a memory **23** for temporarily storing intermediate results.

The original image memory **21** stores the image size (x,y) of the original image, the number of spectral bands of each pixel, data accuracy for each component of a color image, and the like. The intermediate result memory **23** stores scala coefficient s K the number of which is equal to the number of scales; the x components (the horizontal vector component **10a**, see Figure **5B**) of the image information on the surround pixels over the maximum scale length; the y components (the vertical vector component **10b**, see Figure **5C**) of the image information on the surround pixels over the maximum scale length × the width of the image; and the like.

The fast MSR operation apparatus **22** carries out the MSR operation at a high speed based on the surround functions the number of which is equal to the number of scales. As described above, the approximation of each surround function; a reduction in the number of accesses to obtain information on the surround function; the fast

calculation of the scala coefficient K; a reduction in the number of times of sampling the image information on the surround pixels; the omission of the convolution operation; the simplification of the log operation; and the like.

Figure 15 is a flowchart for explaining the operation of the above-described lightness correction system. In the lightness correction system, for instance, the retinex operation is carried out for one pixel per 16 (4×4) pixels which is a square group of pixels. Whether the retinex operation is carried out for a subject pixel is decided (step S11). When it is decided that the retinex operation is carried out for a selected subject pixel, the scala coefficient K is calculated for the subject pixel. When the current subject pixel and the previous center point are symmetrical with respect of the center of the image, the scala coefficient K of the current subject pixel is equal to that of the previous subject pixel. The calculation of the scala coefficient K depends on the position of the subject pixel. Therefore, a buffer for holding the scala coefficient K only needs to have a size such that the scala coefficient K for the maximum large scale can be held.

After the calculation of the scala coefficient K, image information on the surround pixels is updated (step **S13**). For the updating, image information with respect to the previous subject pixel, which is positioned to the left or up of the current pixel, are used again. One-dimensional convolution operation is then carried out based on the updated image information on the surround pixels (step **S14**).

After the one-dimensional convolution, 16 pixels including the subject pixel are subjected to the operation based on expression (1) (step **S15**). The log operation is carried out using the above-described approximation. Thereafter, a correction value is calculated for the result of the retinex operation (step **S16**). The result of the retinax operation is corrected with the correction value. The above-described operation is repeated for the overall pixels to correct the lightness of the image (step **S17**).

According to the method of the present invention for correcting the lightness of an image, the calculation amount for correcting the lightness of each pixel using

the MSR is significantly reduced. In addition, the number of accesses to a memory is significantly reduced. The processing time is thus significantly reduced. Further, necessary memory capacity is reduced, so that a memory having a small capacity can be used, thereby obtaining a low-cost correction apparatus.

Various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.

WHAT IS CLAIMED IS:

1. A method for correcting lightness of an image using a multiscale retinex wherein lightness of a subject pixel of an original image is corrected using a convolution operation of a surround function and surround pixels with respect to the subject pixel of the original image, and the convolution operation is performed over a plurality of scales; and

the surround function has a simplified model such that a value of the surround function is changed in a stepwise way along two axes orthogonal to each other.

2. A method according to claim 1, wherein a sum of image information on the surround pixels positioned at the same distance from the subject pixel and the surround function based on a one-dimensional scale size, the value of the surround function changing in a stepwise way, are subjected to the convolution operation, and a result of the convolution operation is used as a result of another convolution operation.

3. A method according to claim 1, wherein the image information on the surround pixels are read as horizontal

and vertical vector components changing along the two axes in a stepwise way.

4. A method according to claim 1, wherein a scala coefficient K of the surround function used in the convolution operation is calculated based on data dependency on the scala coefficient K previously calculated.

5. A method according to claim 1, wherein the number of the surround pixels to be read out is decreased to reduce the calculation amount of sum-of-products operation in the convolution operation.

6. A method according to claim 1, wherein only one subject pixel is selected with respect to a pixel group consisting of a number of pixels; the convolution operation is performed for the subject pixel; the result of the convolution operation is used as a result of the convolution operation for the other pixels in the pixel group.

7. A method according to claim 1, wherein the log operation in the multiscale retinex is approximately

calculated based on a predetermined graph.

ABSTRACT OF THE DISCLOSURE

A method is provided for correcting lightness of an image using a multiscale retinex. Lightness of a subject pixel of an original image is corrected using a convolution operation of a surround function and surround pixels with respect to the subject pixel of the original image, and the convolution operation is performed over a plurality of scales. The surround function has a simplified model such that a value of the surround function is changed in a stepwise way along two axes orthogonal to each other.

FIG. 1A

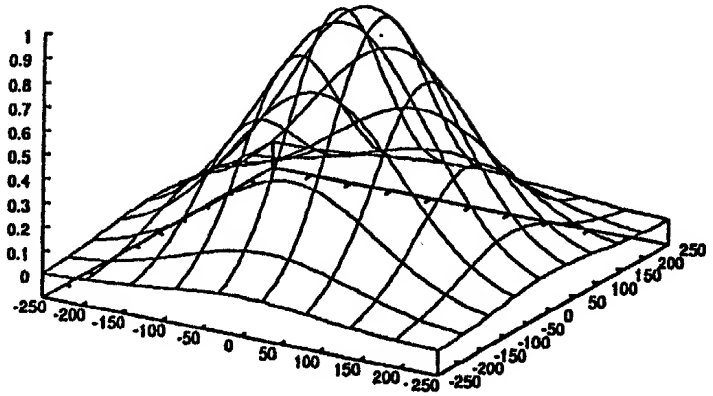


FIG. 1B

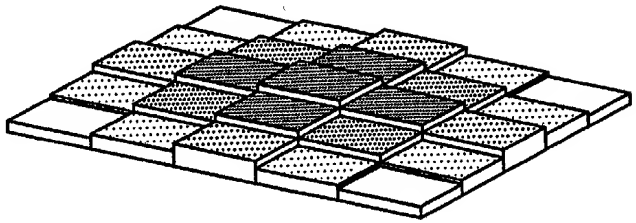


FIG. 1C

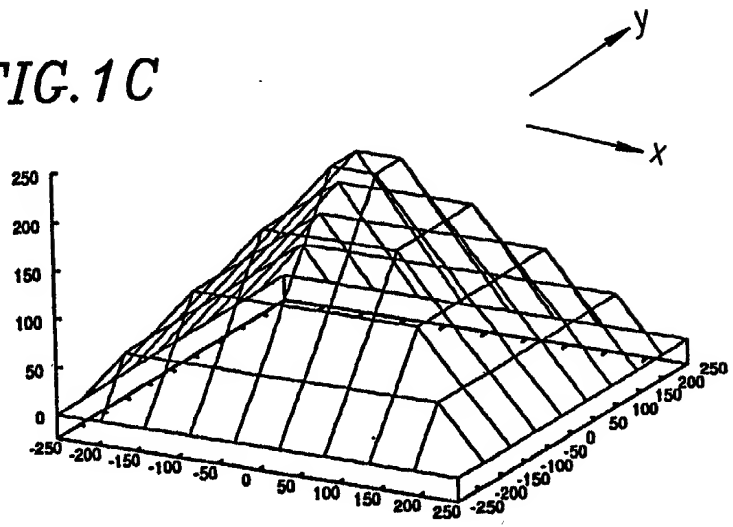
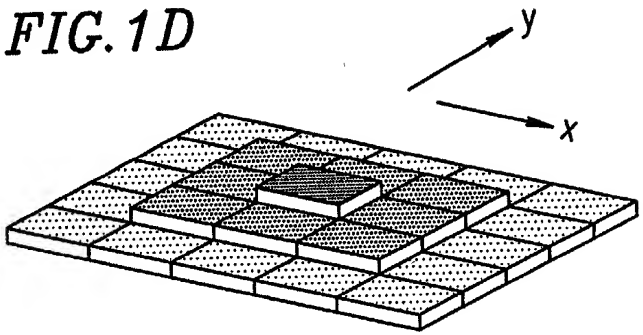
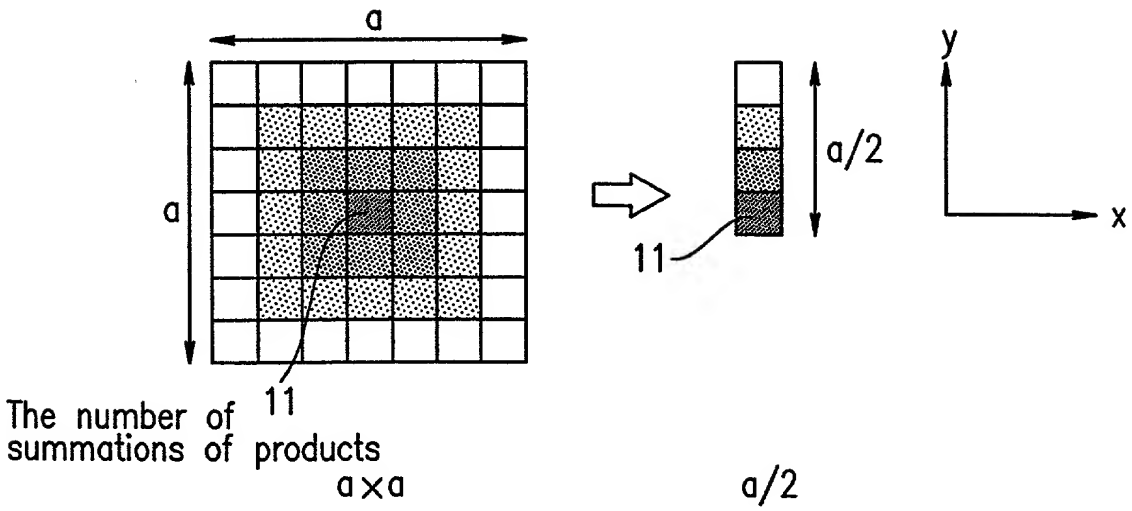


FIG. 1D



00R00087

FIG.2



00R00087

FIG. 3

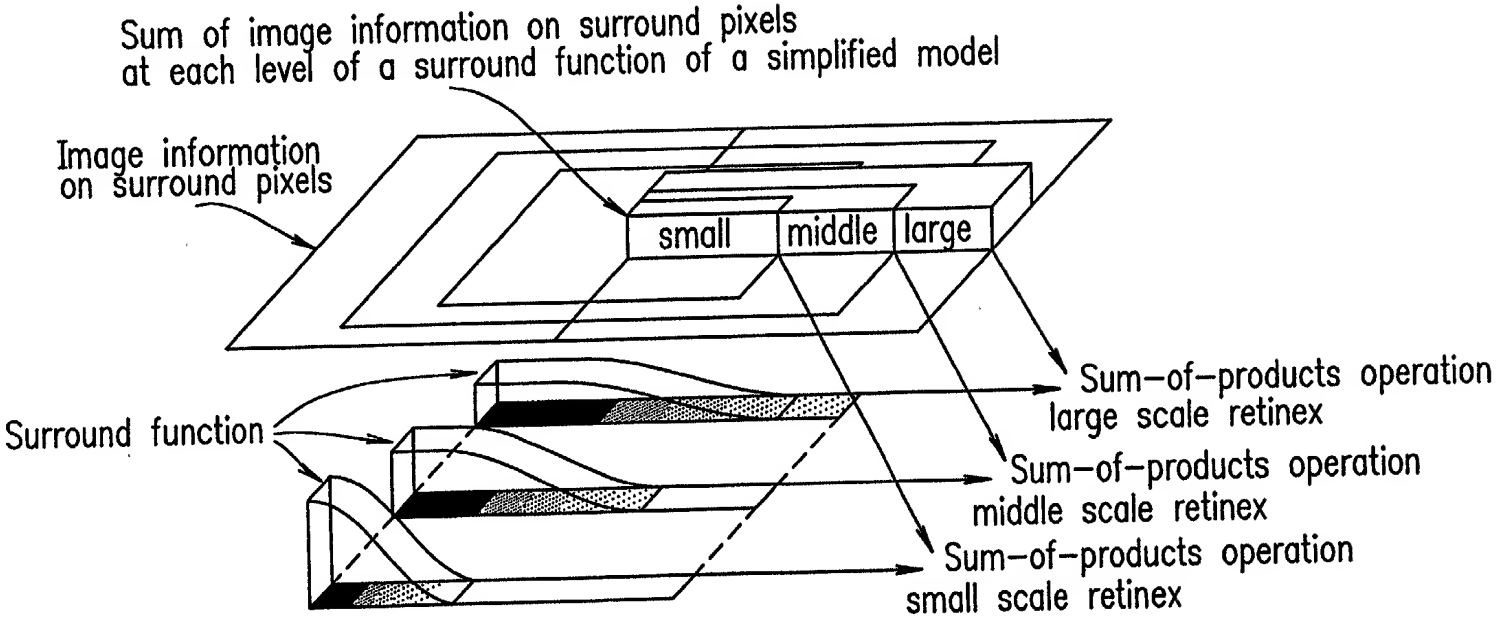


FIG. 4

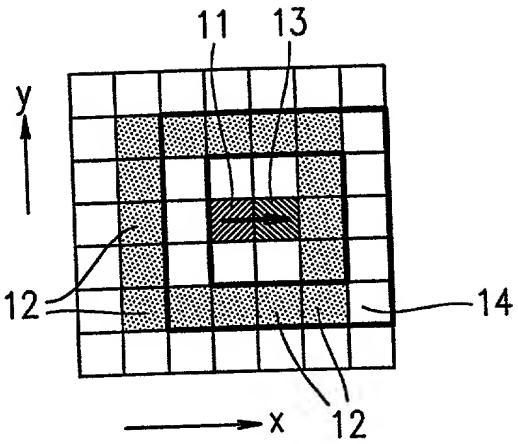


FIG.5A

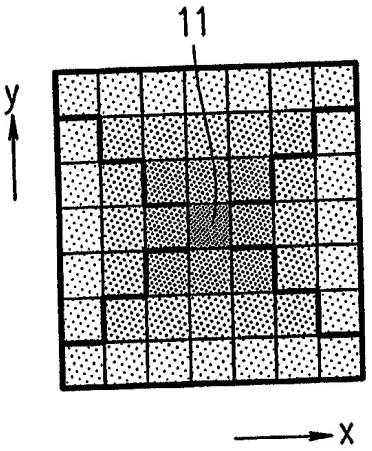


FIG.5B

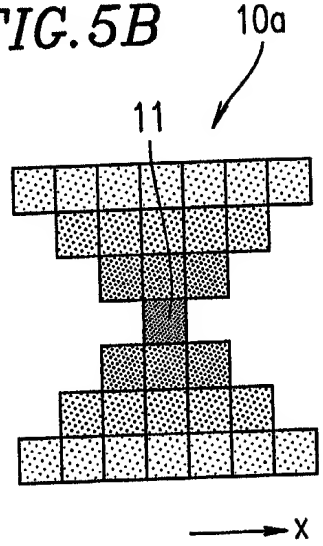
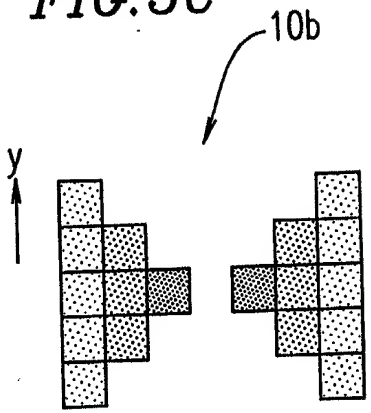


FIG.5C



00R00087

FIG. 6A

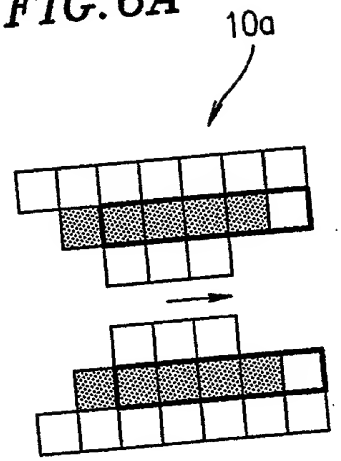


FIG. 6B

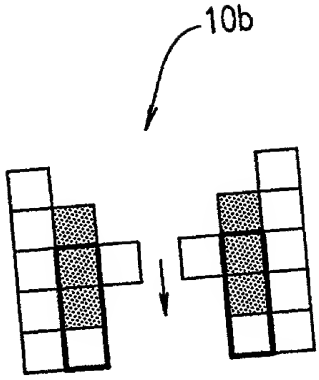
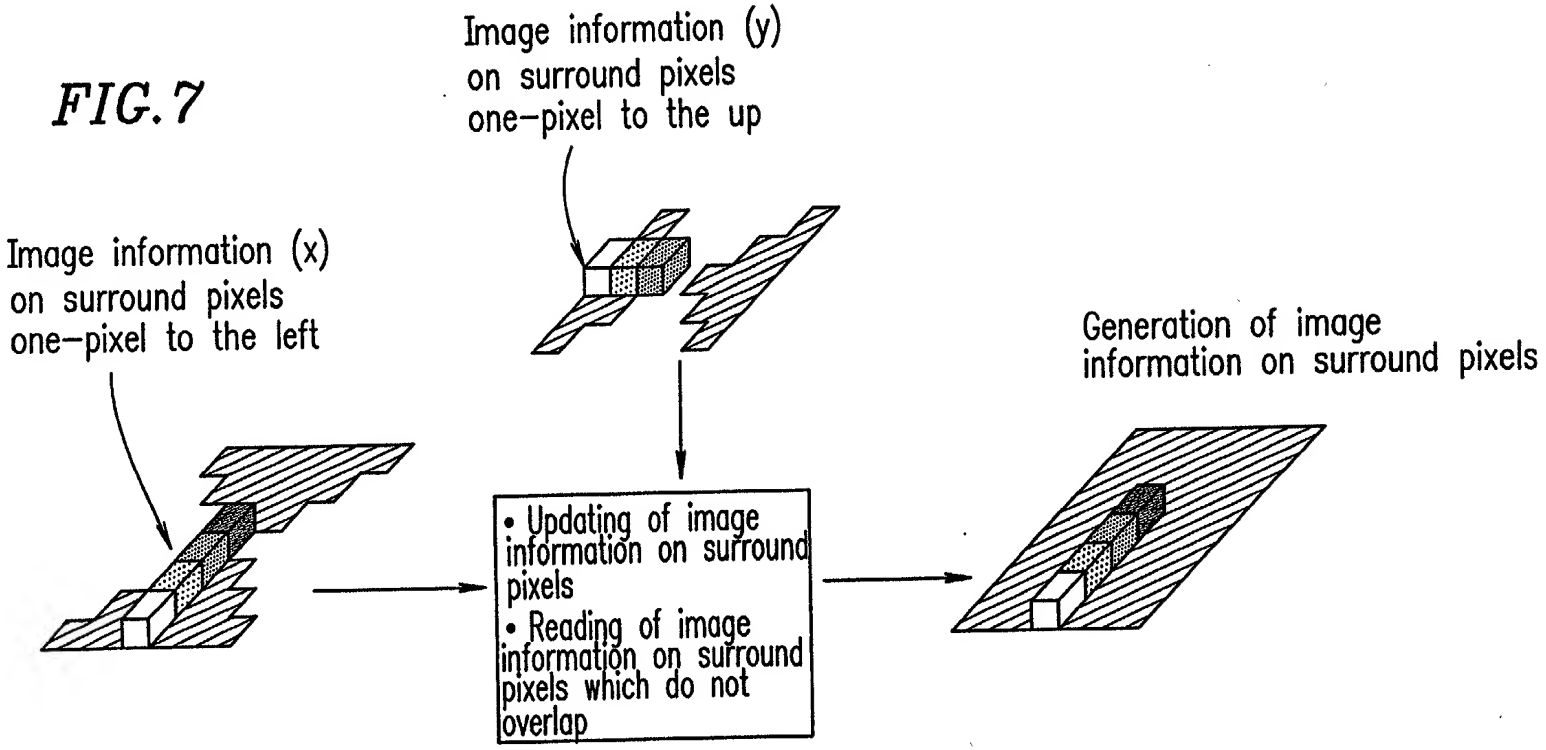


FIG. 7



00R00087

FIG. 8A

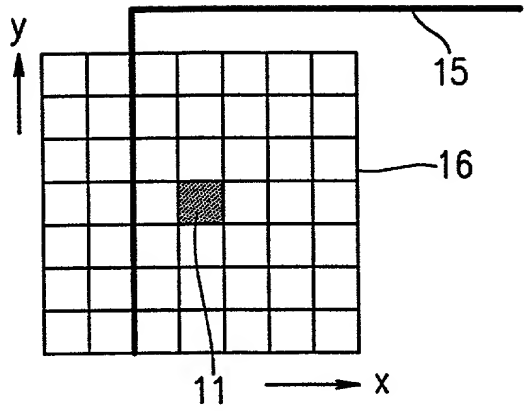
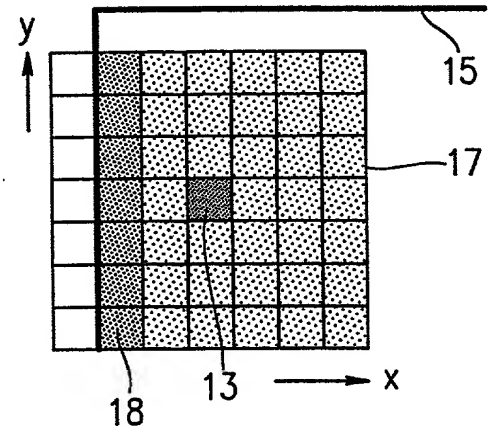
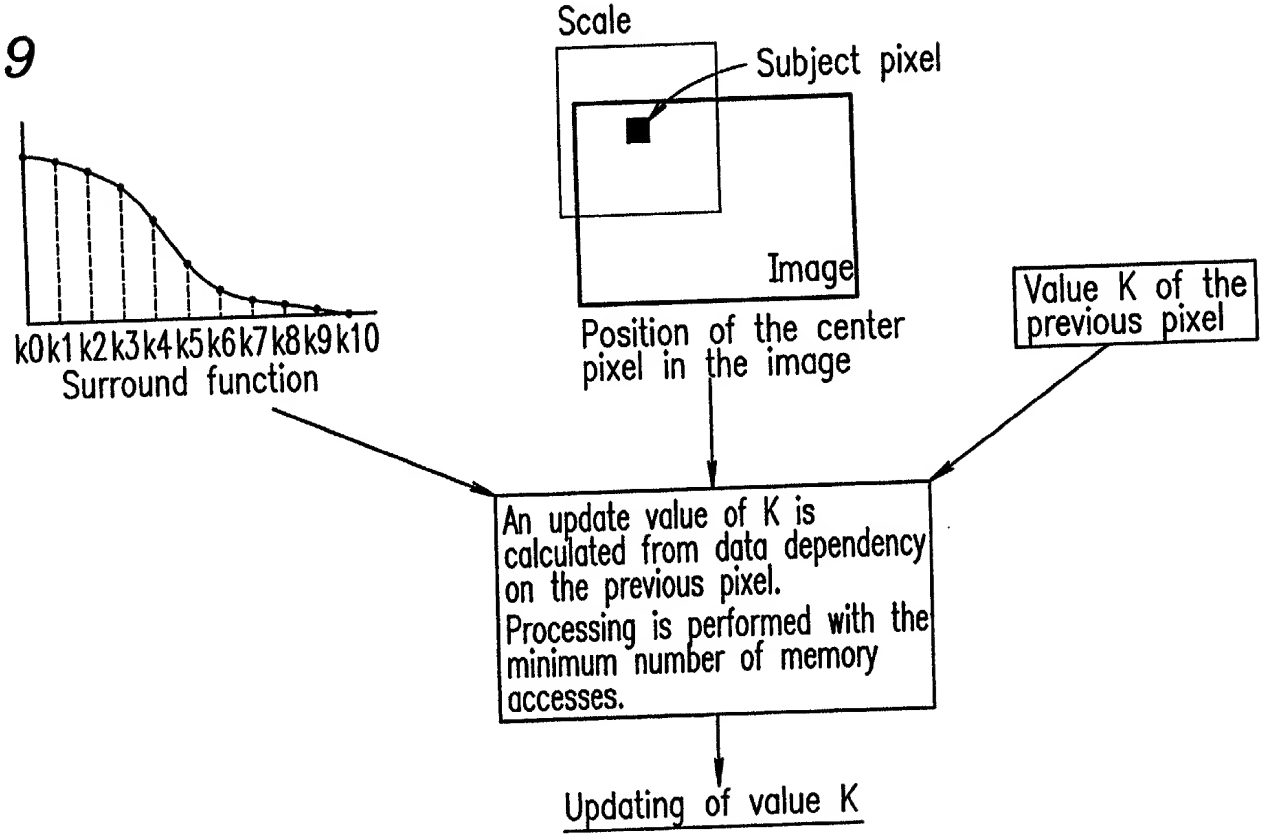


FIG. 8B



SCREEN-1CFC3363

FIG. 9



00R00087

FIG. 10

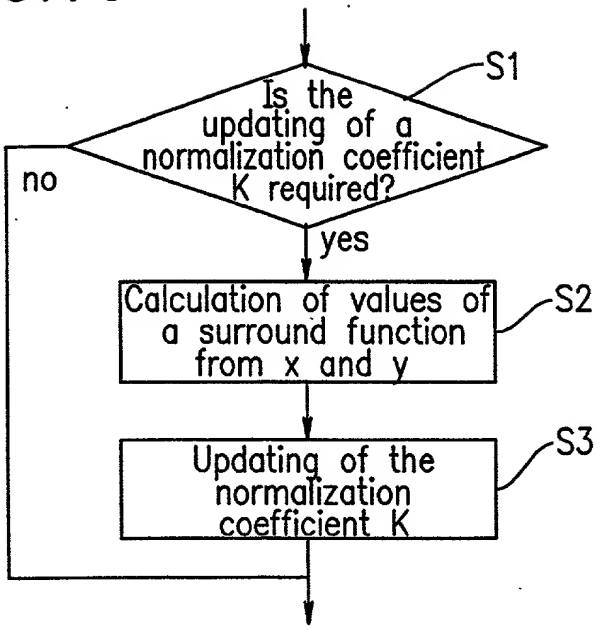

S1
Is the updating of a normalization coefficient K required?
no
yes
Calculation of values of a surround function from x and y
S2
Updating of the normalization coefficient K
S3

FIG. 11

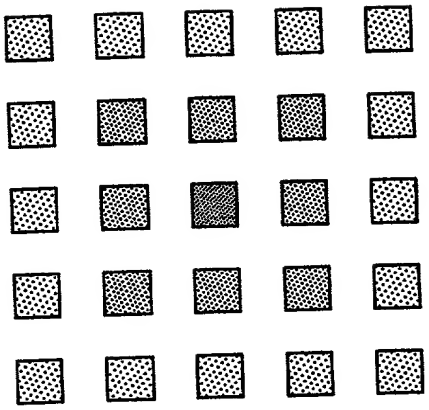


FIG. 12

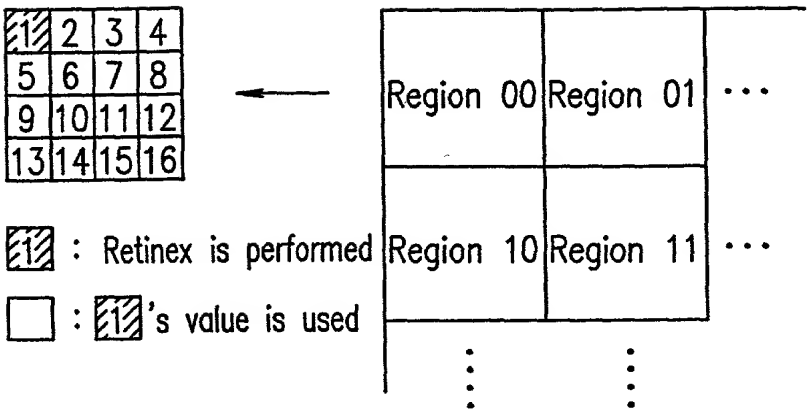

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
: Retinex is performed
: 's value is used
Region 00
Region 01
Region 10
Region 11

FIG. 13A

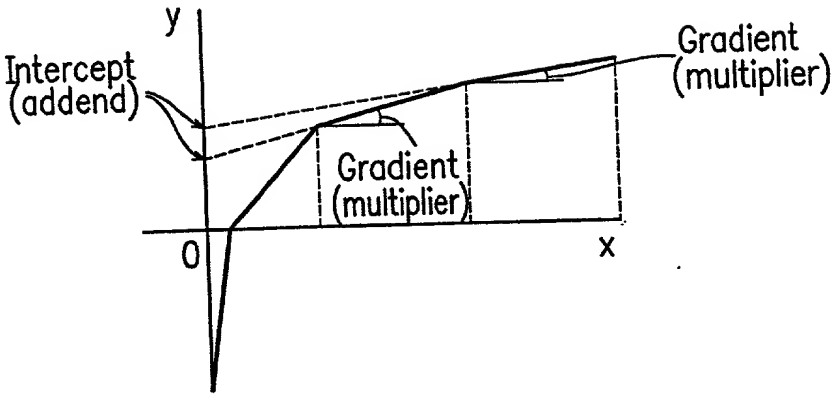


FIG. 13B

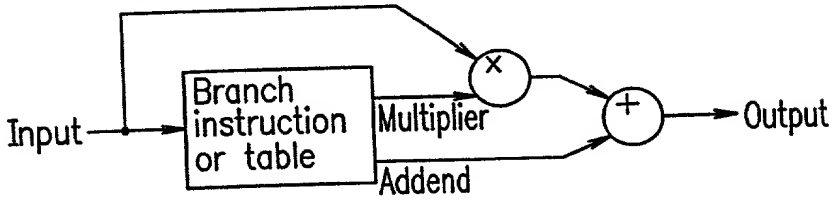


FIG. 14

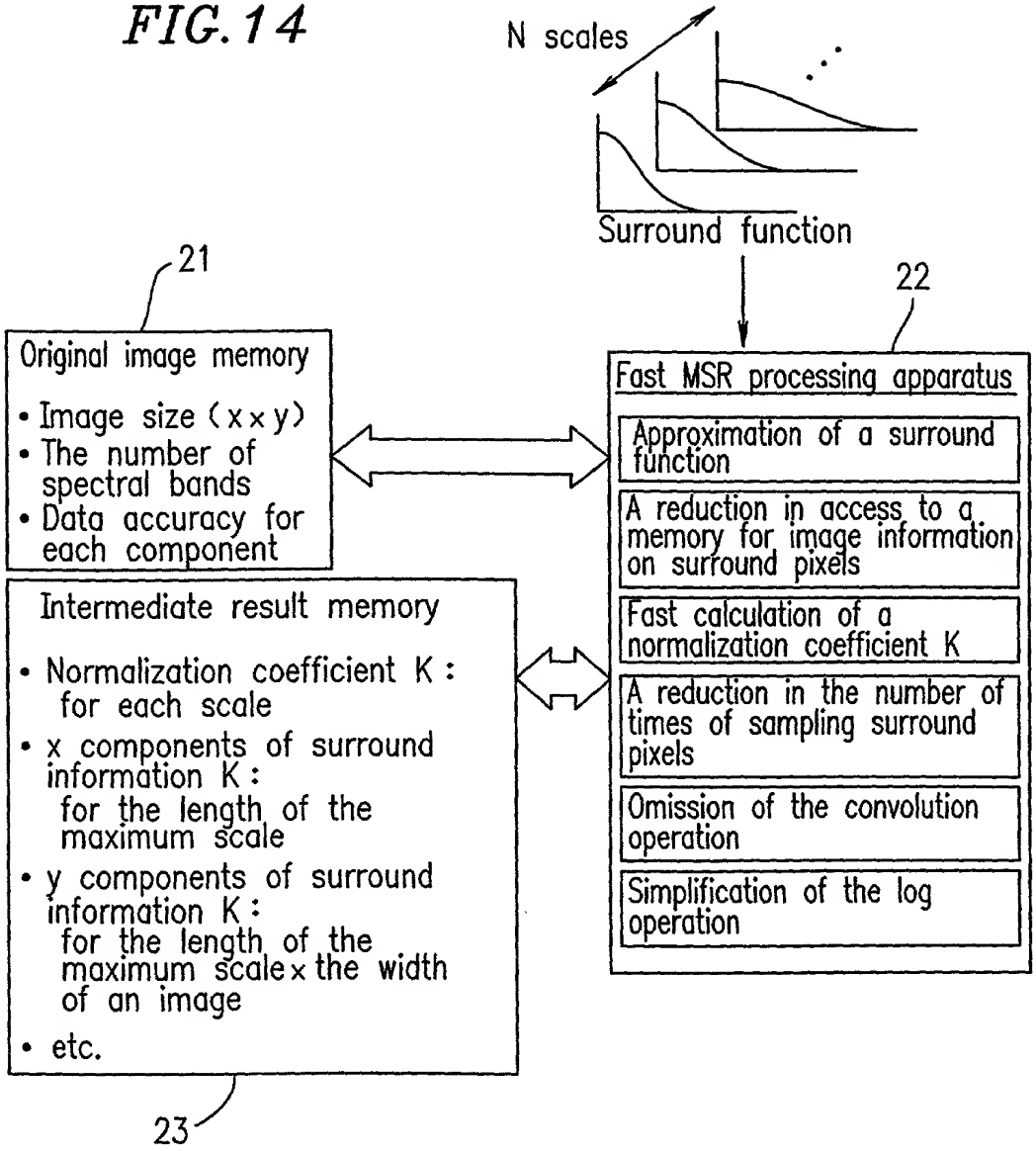
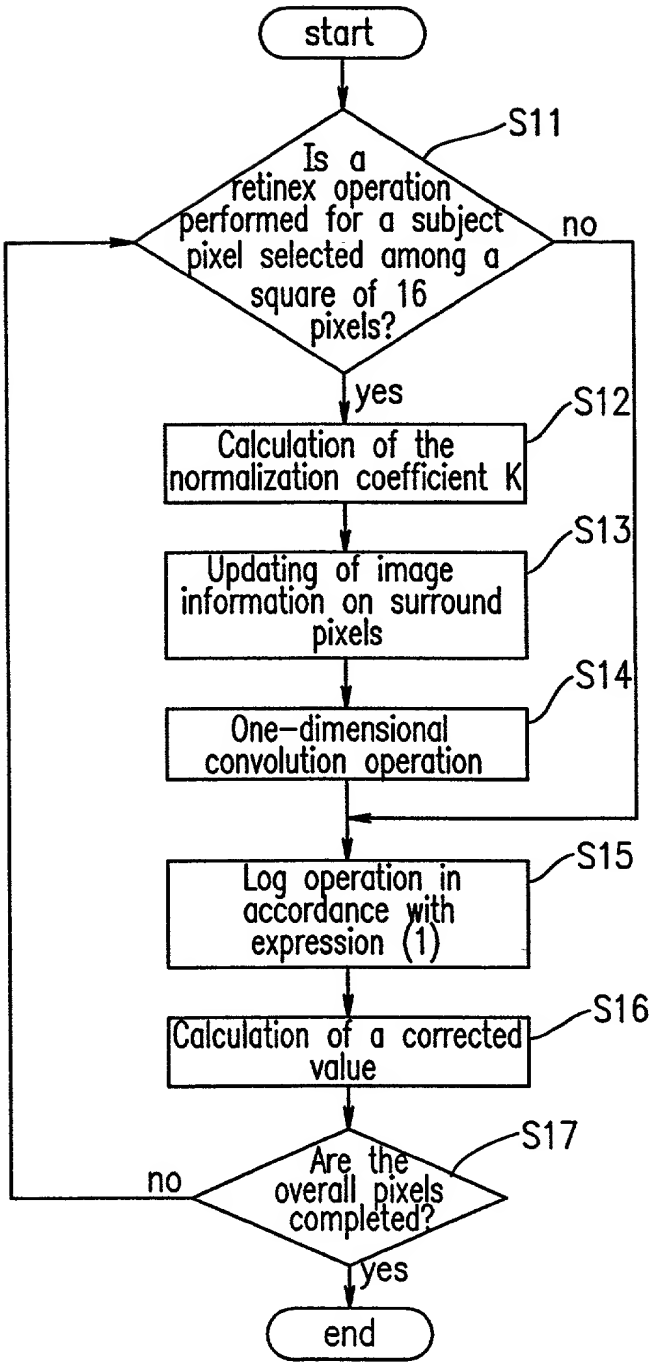

N scales
Surround function
21
22
Original image memory
• Image size (x x y)
• The number of spectral bands
• Data accuracy for each component
Fast MSR processing apparatus
Approximation of a surround function
A reduction in access to a memory for image information on surround pixels
Fast calculation of a normalization coefficient K
A reduction in the number of times of sampling surround pixels
Omission of the convolution operation
Simplification of the log operation
Intermediate result memory
• Normalization coefficient K : for each scale
• x components of surround information K : for the length of the maximum scale
• y components of surround information K : for the length of the maximum scale x the width of an image
• etc.
23

FIG. 15


start
S11
Is a retinex operation performed for a subject pixel selected among a square of 16 pixels?
no
yes
S12
Calculation of the normalization coefficient K
S13
Updating of image information on surround pixels
S14
One-dimensional convolution operation
S15
Log operation in accordance with expression (1)
S16
Calculation of a corrected value
S17
Are the overall pixels completed?
no
yes
end